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The auroral rays

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Abstract—A band which appeared over College (Alaska) on the night of March 24, 1962, provided an excellent chance to examine the ray structure of the aurora. Photographs of the bottom edge of the band suggest that the auroral rays are a small-scale folding structure produced by a positive space charge within the auroral electron sheet-beam. It seems unlikely however that the auroral draperies are related to the same type of instability.

ONE of the most characteristic features of the polar aurora is the ray structure superposed on its curtain-like form. The length of the rays is usually of order 50–300 km and the "diameter" is of order 0·5–5 km. It seems that the nature of the rays has not been much discussed in earlier literature,* although STØRMER (1955) had already speculated that the ray structure sometimes can only be apparent. He suggested also that if a thin auroral curtain structure is folded into a zigzag form, the brightness at a great distance in a direction normal to the curtain is tripled, giving rise to an apparent series of rays superposed on a weak arc or band.

A band which appeared over College (Alaska) between 2300 and 2400 hours on March 24, 1962, provided an excellent chance to examine the ray structure. The band was so located that its bottom edge around the magnetic zenith and the surface of the band about 50 km away from the zenith point and beyond, were seen simultaneously.

When the band was diffuse and homogeneous, the bottom edge was almost a straight line. However, when the band became a little active and the ray structure appeared on a large portion of the surface and quite possibly on the surface around the zenith, the bottom edge waved in various ways. Such activity was repeated many times, with intervening calm intervals.

During the active period, a series of simple waves was first seen. They became quickly folded as if by some nonlinear action upon them. Figure 1 shows one deformed bottom edge around the zenith.†

Fortunately two bright stars, α and β of Ursa Major, appear on the photograph; assuming the height of the bottom edge to be 100 km, there the lines of sight to the two stars are 9·6 km apart. Seen sideways where their vertical extent can be observed, the folded portions would look like real columns of light, namely the so-called rays.

In this connection, we note WEBSTER's experiment (1957) in which he demonstrated that a thin electron sheet-beam often breaks up into an array of vortex-like filaments. He suggested that the auroral rays could be produced by such sheet-beam instability. The instability is produced by a space charge within the sheet-beam.

* Chamberlain (1956) had once suggested a discharge mechanism for the rays.

† Lens $f = 1{\cdot}5$; wide angle; film, high-speed Ektachrome (ASA 160), exposure time 1 sec.

and was first suggested by ALFVÈN (1950). An electrostatic field $\boldsymbol{E}$ due to the space charge, together with the earth's magnetic field $\boldsymbol{H}$ perpendicular to it, causes a drift motion (of velocity $\boldsymbol{v}$) of the beam particles

$$\boldsymbol{v} = \frac{\boldsymbol{E} \times \boldsymbol{H}}{H^2}$$

It can be shown that the folds in Fig. 1 develop where there is a positive space charge (see Fig. 2). The exponential growth rate γ (i.e. $e^{\gamma t}$) for this type of

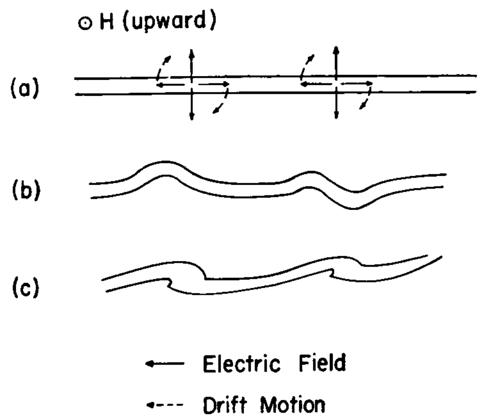

Fig. 2. Schematic diagram to show the growth of an instability of auroral electron sheet-beam due to a positive space charge in it (looking up the bottom edge of the beam in the northern auroral zone).

instability of an infinitely thin sheet-beam is given (EPSTEIN, 1956; GOULD, 1960; KERN and VESTINE, 1961) by

$$\gamma = \frac{\sigma_0}{2\varepsilon_0 B}\beta$$

where $\beta = 2\pi/\lambda$ (λ = the wave length) and σ_0 denotes the charge per unit area in the rationalized mks units. Taking, as a typical example,

$$\gamma = 1/\text{sec}$$
$$\lambda = 1\ \text{km}\ (= 10^3\ \text{m})$$
$$B = 0{\cdot}6\ \text{G}\ (= 6 \times 10^{-5}\ \text{Wb/m}^2)$$

and assuming that the charge is distributed in a layer of thickness 500 m, the number density of positively charged particles is $2{\cdot}1 \times 10^{-3}/\text{cm}^3$. Further, considering an infinitely long cylinder of radius 250 m, with proton number density $2{\cdot}1 \times 10^{-3}/\text{cm}^3$, the radial electric field intensity E at the surface of the cylinder is of order $4{\cdot}7$ V/km ($= 4{\cdot}7 \times 10^3$ e.m.u.). Such an electric field will cause charged particles of either sign within the cylinder to travel clockwise round the axis of the cylinder (as seen looking up towards the bottom edge of the aurora in the northern auroral zone); this speed of travel round the axis is of order E/B = 80 m/sec. This seems to be a reasonable value to explain the growth of the folding.

Rocket observations indicate an intense electron flux ($5 \times 10^{10}/\text{cm}^2$ sec) within visible auroras; such a flux can provide at least 75 per cent of their brightness (MCILWAIN, 1960). Hence an auroral beam must consist largely of electrons.

Fig. 1. Photograph of the bottom edge of a band taken at College (Alaska) between 2300 and 2400 hours on March 24, 1961. Five stars of Ursa Major appear on the photograph. The top, right, bottom and left sides are on the directions N, W, S and E.

Because the growth of the folding is clockwise, it is inferred that the negative charge carried by the electrons in the beam must be compensated by some mechanism, at least within quiet arcs. The folding structure must then be produced by a non-uniform and electrically uncompensated positive charge within the electron sheet-beam.

It is not certain at present how the positive charge in the electron beam is related to the incoming protons. It is known that in the spectra of rayed arcs or bands the hydrogen lines are absent or weak (FAN and SCHULTE, 1954; REES, BELON and ROMICK, 1961). However, it is at least possible that an active rayed arc or band contains a significant space charge. Such a space charge may also be important for producing auroral electrojets, because the jets appear only when an arc or band has the rays and is quite active.

The rate of growth of this particular instability is largest for wave lengths λ about eight times the beam thickness (GOULD, 1960). For an active auroral curtain, the thickness is of order 150–350 m (AKASOFU, 1961), so that the "diameter" of the apparent rays is of order 1·2–2·8 km. Even for a diffuse and quiet arc, it is not likely to be more than 10 km. This is of the right order for auroral rays. On the other hand, the characteristic length of the draperies is usually much larger, often at least 100 km. ALFVÉN (1950) suggested that space charge could produce auroral instability, and attributed the auroral *draperies* to this cause; the considerations here given suggest that such instability may explain the rays but not the draperies.

The explanation of auroral rays here suggested rests on the assumption that a local space charge and electric field are present in the auroral sheet. There is need for an explanation of the origin of such a space charge, or for observational evidence of its existence.

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